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# **REISSUE PATENT APPLICATION TRANSMITTAL**

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APPLICATION FOR REISSUE OF: (check applicable box)	Utility Patent Design Patent Plant Patent
APPLICATION ELEMENTS	ACCOMPANYING APPLICATION PARTS
* Fee Transmittal Form (PTO/SB/56)     (Submit an original, and a duplicate for fee processing)	7. Foreign Priority Claim (35 U.S.C. 119) (if applicable)
2. XX Specification and Claims (amended, if appropriate	8. Information Disclosure Copies of IDS Statement (IDS)/PTO-1449 Citations
3. XX Drawing(s) (proposed amendments, if appropriate	e) 9. English Translation of Reissue Oath/Declaration (if applicable)
4. Reissue Oath / Declaration (original or copy) (37 C.F.R. § 1.175)(PTO/SB/51 or 52)	10. Statement(s) Statement filed in prior application, Statement(s) Status still proper and desired
5. Original U.S. Patent Offer to Surrender Original Patent (37 C.F.R. § 1.:	(PTO/SB/09-12)  11. Preliminary Amendment
(PTO/SB/53 or PTO/SB/54) or Ribboned Original Patent Grant	12. XX Return Receipt Postcard (MPEP 503) (Should be specifically itemized)
Affidavit / Declaration of Loss (PTO/SB/55)	13. XX Other: Request to Transfer Drawings
6. Original U.S. Patent currently assigned?	
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Written Consent of all Assignees (PTO/SB/53 or 5  37 C.F.R. § 3.73(b) Statement Power of Attorney	54)  I NOTE FOR ITEMS 1 & 10: W ORDER TO BE ENTITLED TO PAY SMALL ENTITY FEES, A SMALL ENTITY STATEMENT IS REQUIRED (37 C.F.R. \$ 1.27), EXCEPT IF ONE FILED IN A PRIOR APPLICATION IS RELIED UPON (37 C.F.R. \$ 1.28).
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### HIGH EFFICIENCY, HIGH POWER DIRECT DIODE LASER SYSTEMS AND METHODS THEREFOR

## BACKGROUND OF THE INVENTION

The present invention relates generally to diode laser array systems. More specifically, the present invention relates to high efficiency, high power direct diode laser systems.

In numerous applications such as laser tracking, laser guidance and laser imaging, it is desirable to produce a high power coherent laser output. Moreover, high power coherent laser systems find applications in such diverse fields as offensive and defensive weapon systems, e.g., non-visible light illuminators for special operation forces and protective laser grids, as well as material processing, e.g., welding, cutting, heat treating and ablating, and medicine, e.g., surgical and diagnostic aides.

In the earliest laser systems, single semiconductor lasers were utilized to provide a coherent source of laser output. These single semiconductor lasers were limited in the amount of power which they could provide due to their structural limitations and limited efficiency. More recently, arrays of semiconductor lasers have also been utilized in which adjacent emitters of the array of semiconductor lasers spaced upon the same substrate are coupled together. One such laser array system was disclosed in commonly assigned U.S. Pat. No. 5.212,707 to Heidel et al., which is incorporated herein by reference for all purposes.

FIG. 1 illustrates a one-dimensional semiconductor laser array 10 according to U.S. Pat. No. 5,212,707, which is mounted on a heatsink 12. The semiconductor laser array 10 has an associated lens assembly 22, 24 for collimating the laser array's output, which is positioned adjacent to the emitting facet of the semiconductor laser array 10. Lens assembly 22, 24 is attached to the ears 25 of the heatsink 12. The emitters 20 of the array 10 are supplied with power from an external power supply via wires 18, a standoff pad 16 and a power lead 14. In an exemplary case, the semiconductor appear array 10 shown in FIG. 1, includes ten individual emitters 20; and number of emitters 20 may be employed as determined by the requirements of the particular application.

Once the semiconductor laser array 10 has been fabricated, mounted and powered, the output of the semiconductor laser array's emitters 20 must be collimated in order to obtain the desired collimated output. The lens assembly, as shown in FIG. 1, which is designed to collimate the output of the semiconductor laser array 10, includes a first refractive lens 22, typically of a biconvex design, and a second binary optical element 24, which is essentially a diffractive lens. The refractive biconvex lens 22 collimates the fast axis of each emitter 20 while the binary optical element 24 serves to collimate the slow axis of each emitter 20 and correct all spherical aberrations including those introduced by the collimation performed by the refractive lens 22.

The binary optical element 24 includes a substrate on which a binary optical diffraction pattern 26 is etched. Generally, the materials of the refractive lens 22 and the 60 binary optical element 24 have substantially equivalent refractive indices such that minimal refraction occurs at the interface between the refractive lens 22 and the binary optical element 24. The binary optical element 24 has a back surface 27 positioned adjacent to the front surface 28 of the 65 refractive lens 24 and a front surface 28 on which the binary optic diffraction pattern 26 is etched. Since the binary optical

diffraction pattern 26 is produced in accordance with typical binary optic technology, as well known to those of ordinary skill in the art (See U.S. Pat. No. 4,846,552.), further discussion of this technology will not be provided.

The binary optic diffraction pattern 26 is typically an eight phase level structure (although a two, four, or sixteen-phase level structure could also be utilized) which corrects for optical path differences inherent in the divergent output light of an emitter of a semiconductor laser array. Thus, the rays of light which exit the binary optic element 24 will have all travelled equal optical pathlengths, defined as a physical pathlength multiplied by the index of refraction of the material through which the light rays travelled which are equal or varied from that equal optical pathlength by only an integer multiple of the wavelength of the light being emitted. An eight level binary optic diffractive pattern 26 is shown schematically in FIG. 1.

A two-dimensional semiconductor laser array can be fabricated from a plurality of the one-dimensional semiconductor laser arrays 10 shown in FIG. 1. The one-dimensional semiconductor laser arrays 10 are stacked as shown in FIG. 2 within a heatsink which serves as a holding or clamping fixture 70. The clamping fixture 70 is designed such that the one-dimensional semiconductor laser arrays 10 may be stacked on top of one another so that the outputs of each one-dimensional semiconductor laser array are substantially parallel to the outputs of the other semiconductor laser arrays.

Once the one-dimensional semiconductor laser arrays 10 have been mounted within the clamping fixture 70, the collimating lenses are aligned and attached. The fabrication of the collimating lenses is done in a manner identical to that previously discussed such that the refractive lens 22 is cemented to the binary optical element 24 which has been designed to collimate the laser output of each emitter 20. The alignment and attachment of the collimating lenses is accomplished in a sequential fashion for optimum efficiency. The collimating lenses 80a associated with the first one-dimensional semiconductor laser array 10a are positioned as previously described such that the optical axes of each emitter 20 of the semiconductor laser array 10 are substantially aligned with the center of the collimating lens assemtially aligned with the center of the collimating lens assem-

bly 80a.

The second collimating lens assembly 80b is then placed 45 in front of a second one-dimensional semiconductor laser array 100 and is held in position by means of a vacuum chuck 76 connected by a vacuum line to a vacuum source. as shown in FIG. 3. The two-dimensional semiconductor laser array 10 is then supplied power such that the emitters 50 20 produce a light output. A transform lens 72 is positioned within the path of the light emitted from the first and second one-dimensional semiconductor laser arrays. The transform lens 72 may be a plano-convex or a biconvex lens, as shown in FIG. 3, such that a simulated far field will appear at the 55 focal plane of the transform lens 72 when the input light to the transform lens 72 is collimated. To determine the simulated far field, when all beams of light overlap at the focal plane of the transform lens 72, a line scan detector 74 is positioned at the focal plane. The output of the line scan 60 detector is monitored to determine if proper collimation has been achieved. The position of the second collimating lens assembly 86b is varied until proper collimation is observed at the focal plane of the transform lens. Once proper collimation is observed, the position of the second collimat-65 ing lens assembly 80b is preserved by fixing the lens assembly in position in the ears 25 of the clamping fixture 70. An identical alignment procedure is done for each lens assembly and its corresponding one-dimensional semiconductor laser array 10, until the lens assembly for each semiconductor laser array 10 has been properly aligned such that the light is collimated and focused at the simulated far

The two-dimensional laser array when properly supplied with power produces a single collimated spot of laser output in the far field. By utilizing a plurality of one-dimensional semiconductor laser arrays 10 whose outputs may be combined, the output power of the two-dimensional semiconductor laser array may be quite high. For example, 25 watts of continuous wave laser energy was produced by a two-dimensional semiconductor laser array consisting of twelve one-dimensional semiconductor laser arrays with each one-dimensional semiconductor laser array having 15 twenty one emitters. Additionally, the overall efficiency of the laser array from electrical input to power in the central lobe was approximately 26%.

U.S. Pat. No. 5,299,222 discloses an alternative approach to producing a high power laser diode system that collects 20 and concentrates laser output from a stack of diode laser bars in a form that is useful and flexible for pumping a laser, e.g., a solid state laser. As shown schematically in FIG. 4. the light beam output of stacked diode laser bars is coupled into a plurality of optical fibers. The output light beams from the 25 fibers may be used to pump a laser resonator. The fibers can be grouped at various end points of a solid-state laser cavity for efficient end-pumping. In FIG. 4. a light beam 11 is emitted by a plurality of diode laser bars in a diode laser bar stack 13, and light from a selected group of the bars is 30 collected by one of a plurality of cylindrical lenses 15 positioned adjacent to but spaced apart from each diode bar in the stack 13. Each diode laser bar may have an aspect ratio (length-to-width) as high as 10,000:1, or even higher, and the cylindrical lenses 15 are interposed to reduce the beam 35 divergence angle in a first direction, relative to the beam divergence angle in a second, perpendicular direction, so that the resulting beam divergence angle in each of the two directions is roughly the same.

Two or more turning mirrors 17A, 17B, 17C and 17D 40 separate mutually exclusive portions of the light beam 11 into non-overlapping light beam components 19A, 19B, 19C and 19D, respectively, and at least one pump light beam component, such as 19E, is optionally defined by a portion of the light beam 11 that does not encounter a turning mirror. 45 Each light beam component 19A, 19B, 19C, 19D and 19E is then focussed by suitable focusing optics 21A, 21B, 21C, 21D and 21E, respectively, into a corresponding multimode optical fiber 23A, 23B, 23C, 23D and 23E, respectively, with the diameters of the fibers being chosen to fully capture the 50optical beam intended for that fiber. Preferably, the sine of the convergence angle as a light beam arrives at a lightreceiving end of a fiber is less than the numerical aperture NA of that fiber. In one embodiment, each optical fiber has a diameter of about 500 µm, but this fiber diameter may be 55 as large as a few mm. Each of the focusing optics 21j (j=A, B, C, D or E) may be a lens with a short focal length, such as f=6.35 mm, and is intended to cause the resulting beam to converge to an entrance diameter, measured at the entrance of the corresponding fiber 23j, that is about 25 60 percent of the diameter of the portion of the pump light beam 11 that arrives at the focusing optics 21j.

The numerical aperture NA of the multimode fiber 23j lies in the range 0.15-0.3 but may be as high as 0.6. Each optical fiber 23j delivers the component pump light beam propa- 65 gating therein to a selected position and with a selected angular orientation relative to the laser cavity to be pumped

by this collection of component pump light beams. Each optical fiber 23j is provided with an anti-reflective coating at the diode laser wavelength P, and the coating is either applied directly to the fiber end or to a separate glass window that is bonded to the light-receiving end of that fiber. The core material of the fiber 23j may be glass, and the cladding material of the fiber may be glass or plastic, with a smaller refractive index than the core refractive index, which determines by the numerical aperture of the fiber in a manner well known in the art.

It will be appreciated that expansion of the systems discussed immediately above would require both a large amount of real estate and complex optic assemblies to couple the outputs of a plurality of the disclosed output 15 modules to a single spot. For example, the presence of lens 72 in FIG. 3 suggests the need for a focusing lens associated with each module; FIG. 4 suggests that a plurality of lenses 21 are needed to efficiently couple the output of a single diode laser array. It would be desirable for a plurality of 20 semiconductor laser arrays to produce a single spot of high intensity laser output using a simple and robust optical subsystem. Furthermore, it would be desirable for a plurality of semiconductor laser arrays to be mounted evenly and the outputs thereof collimated in such a manner as to fill the 25 available aperture to thereby provide a substantially constant intensity across the single spot of laser output produced.

#### SUMMARY OF THE INVENTION

Based on the above and foregoing, it can be appreciated that there presently exists a need in the art for a diode laser system which overcomes the above-described deficiencies.

An object according to the present invention is to provide a direct diode laser system generating a high fluence level at a workpiece.

Another object according to the present invention is to provide a direct diode laser system which generates a high power laser beam. According to one aspect of the present invention, the high power laser beam can be focused onto a single spot for interaction with a workpiece. According to another aspect of the present invention, the high power laser beam may be directed into one end of a solid state laser.

A still further object of the present invention is to provide a direct diode laser system which generates a high fluence level at a workpiece using dichroic coupling of multiple frequency collimated laser beams. Advantageously, all of the collimated laser beams can be generated using laser diode arrays.

Yet another object of the present invention is to provide a direct diode laser system which generates a high fluence level at a workpiece using both dichroic and polarization coupling of multiple frequency collimated laser beams. Advantageously, all of the collimated laser beams can be generated using laser diode arrays.

An additional object of the present invention is to provide a direct diode laser system which generates a high fluence level at a workpiece by simultaneously coupling thousands of collimated laser diode outputs into a single fiber via a single lens.

Another object of the present invention is to provide a direct diode laser system which generates a linearly scalable high power level output.

These and other objects, features and advantages of the present invention are provided by a direct diode laser system which includes N laser head assemblies (LHAs) generating N output beams, N optical fibers receiving respective ones

of the N output beams and generating N received output beams, and a torch head recollimating and focusing the N received output beams onto a single spot. According to one aspect of the invention, each of the laser head assemblies of the direct diode laser system includes M modules generating M laser beams, wherein each of the M laser beams has a corresponding single wavelength of light, M-1 dichroic filters, wherein each of the M-1 dichroic filter transmits a corresponding one wavelength of the M laser beams and reflects all other wavelengths of the M laser beams and a fiber coupling device collecting the M laser beams to produce a respective one of the N output beams.

These and other objects, features and advantages of the present invention are provided by a direct diode laser system, including N laser head assemblies (LHAs) generat- 15 ing N output beams, wherein each of the N laser head assemblies includes M first modules generating M first laser beams, wherein each of the M first laser beams has a corresponding single wavelength of light, M-1 first dichroic filters defining a first optical waveguide for directing all of 20 the M first laser beams into a first optical path, wherein each of the M-1 first dichroic filters transmits a corresponding one of the M first laser beams having a respective wavelength and reflects all other wavelengths of the M first laser beams. a fiber coupling device disposed adjacent to the first optical 25 path for collecting the M first laser beams to produce a respective one of the N output beams, N optical fibers receiving respective N output beams and generating N received output beams, and a torch head recollimating and focusing the N received output beams on a single spot.

These and other objects, features and advantages according to the present invention are provided by a method for generating a high energy laser beam, including steps for:

 (a) generating P collimated laser beams having an Mth wavelength;

- (b) repeating step (a) M times so as to produce M×P collimated laser beams having M different wavelengths;
   (c) coupling the M×P collimated laser beams into an optical path.
- (d) coupling the M×P collimated laser beams into an ith 40 optical fiber to thereby produce a corresponding ith output laser beam, where i=1 to N;
- (e) repeating steps (a) through (d) N times to thereby generate N output laser beams;
- (f) recollimating the N output laser beams to produce N 45 recollimated laser beams; and
- (g) focusing the N recollimated laser beams onto a single spot.

These and other objects, features and advantages of the invention are disclosed in or will be apparent from the 50 following description of preferred embodiments.

#### BRIEF DESCRIPTION OF THE DRAWINGS

These and various other features and aspects of the present invention will be readily understood with reference to the following detailed description taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a perspective view of a one-dimensional semiconductor laser array assembly, a refractive lens, and a binary optic element;

FIG. 2 is a two-dimensional semiconductor laser array and its associated collimating optics held within a clamping fixture;

FIG. 3 is a side view of a transform lens in a twodimensional semiconductor laser array structure illustrating 65 the proper collimation of laser diode outputs by a collimating lens assembly; FIG. 4 is a schematic view of an optical system used to couple the outputs of a 1 cm length diode laser stack into five separate fibers;

FIG. 5 is a high level block diagram of a high efficiency,
 high power direct diode laser system according to the present invention;

FIG. 6 is a more detailed block diagram of selected components of the high efficiency, high power direct diode laser system shown in FIG. 5;

FIG. 7 is a detailed schematic diagram of the optic bed of one of the assemblies illustrated in FIG. 6, which is useful in understanding one facet of system power scaling according to the present invention;

FIG. 8 is a side view of a diode laser array module which can be employed in an exemplary embodiment according to the present invention; and

FIG. 9 is an illustration of an exemplary configuration of the torch head assembly of FIG. 5.

# DETAILED DESCRIPTION OF THE INVENTION

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FIG. 5 is a high level block diagram of the high efficiency, high power direct diode laser system (DLS) 1 according to alternate preferred embodiments of the present invention. As illustrated in FIG. 5, the DLS 1 includes a power supply 100 providing power to both a controller 200 and N laser head assembly (LHA) controllers generally denoted 300. N laser head assemblies (LHAs) generally denoted 400 receive the output power of the LHA controllers 300, respectively, and provide N optical output laser beams to a torch head 500 advantageously can be augmented by a laser head 510 (See FIG. 9.), and, thus, the alternative designation in FIG.

Preferably, the number N of LHA controllers 300 and LHA's 400 can be varied as required to provide a desired output power of the DLS 1. In an exemplary case, 4 LHA 40 controllers 300A, 300B, 300C and 300N providing electrical power to 4 LHAs 400A, 400B, 400C and 400N, respectively, are included in the DLS 1. The block diagram of FIG. 5 illustrates a DLS 1, in which the optical output laser beams of 4 LHAs 400, each producing 800 watts of 45 power, are combined to deliver over 3200 watts of cw power to a single focusing lens. As discussed in greater detail below with respect to FIG. 9, the output of each respective LHA 400 advantageously can be fiber coupled and at the distal end of each fiber (approximately 1 mm diameter) they 50 can be recollimated. The 4 collimated laser sources, i.e., the 4 output optical beams, preferably are collected by a single lens, which focuses the 3200 watts of total power onto a single point. It will be appreciated that this latter technique is commonly used in industrial laser systems to increase 55 fluence on the work piece.

In an exemplary embodiment of the DLS 1 of FIG. 5, the power supply provides DC power to controller 200 and LHA controllers 300. Preferably, controller 200 acts as a master controller with respect to the N LHA controllers 300, which act as slave controllers. It should also be mentioned that each of the N LHA controllers 300 controls and varies the output optical beam of the respective LHA 400, as discussed in greater detail below.

FIG. 6 is an intermediate level block diagram showing additional details of the LHA 400 and torch head 500 components illustrated in FIG. 5. Advantageously, each of the N LHAs 400 includes M diode laser modules 410, of

which the output beams of M/2 modules and combined with the output beams of the other M/2 modules 410 using polarization combiner 450. The combined output beam of each of the N polarization combiners 450 is provided to torch head 500 via fiber coupling optics 460 and a respective optical fiber 470.

Referring now to FIG. 7, a detailed description of an exemplary embodiment of LHA 400 will now be presented. Preferably, M diode laser modules 410 are disposed on a support plate or optic bed 430 in groups of M/2 modules 410, the left and right groups of modules 410 being disposed on opposite sides of a polarization combiner (polarizer) 450. The output beams of the left set of M/2 modules 410 are combined using (M/2)-1 dichroic filters 420 and directed to the reflecting surface of polarizer 450. The output beams of the right set of M/2 modules 410 are combined using an additional (M/2)-1 dichroic filters 420 and directed to the transmitting surface of polarizer 450 via waveplate 440. Polarizer 450 combines the left and right sets of M/2 laser beams produced by the left and right M/2 module sets in a manner well known to those of ordinary skill in the art.

The output beams of the polarizer 450 are transmitted to the optical fiber 470 via fiber coupling optics 460. Advantageously, fiber coupling optics may include a relay mirror 462, a transform lens 464 and a fiber coupler 466, 25 arranged in that order along the optical path of the LHA 400. Preferably, polarizer 450 and the relay mirror 463 provide 2 axis adjustment while the transform lens 464 provides 5 axis adjustment. In the exemplary case illustrated in FIG. 7, waveplate 440 produces polarization rotation of the output 30 beams of the right group of M/2 modules.

Advantageously, each of the left and right sets of modules 410 produce output beams each having a different single wavelength, the wavelength separation between the output beams being only dependent on the quality of the dichroic 35 filters used in the DLS 1. (M/2)-1 of the modules 410 are disposed behind a respective optical bandpass filter 420 which transmits only the output beam from that module and reflects all other wavelengths of light. Since the module is mechanically independent of the associated dichroic filter 420, the dichroic filters 420 can be aligned separately from the modules 410. After all of the modules 410 are combined in wavelength, then the broadband polarizer 450 is used to combine the output beams from the opposing groups of M/2 modules 410 into a single high brightness beam.

As discussed immediately above and as shown in FIG. 7, twelve 100 watt collimated diode laser modules 410, six each in left and right groups, are combined for launching into a single optical fiber. It should be noted that each module 410 in one of the left and right groups of modules 50 410 produces laser light at a single selected wavelength. Preferably, the selected wavelength corresponds to the bandpass wavelength of one of the dichroic filters 420. The selected wavelength preferably is within the range of approximately 450 nm to 2.5 microns, and the selected 55 wavelengths preferably all fall within the 760-1050 nm range, with the range of 800-980 nm being most preferable for the exemplary case illustrated in FIG. 7. It should also be mentioned that the minimum differential wavelength for any two of the modules 410 is approximately 10 nm, which 60 corresponds to the minimum band pass of the dichroic filters 420 available using present technology. Thus, the number M of modules 410 in each LHA 400 is 20 for each 100 nm in bandwidth of the output of torch head 500 when both dichroic filters 420 and polarizer 450 are employed and 10 65 for each 100 nm in bandwidth when only dichroic filters 420 are employed. However, the number M of modules can be

increased as the passband of each of the dichroic filters 420 decreases. It should be mentioned that dichroic filters 420 advantageously can be low, high or band pass filters.

It will also be appreciated that the wavelengths produced 5 by the modules 410 advantageously can be selected to facilitate use of the DLS 1. For example, a single one of the modules 416 can produce a wavelength in the visible portion of the spectrum so as to provide a guide beam for reasons of safety.

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Each of the modules 410 advantageously can be constructed as shown in FIG. 8, wherein a plurality of laser diode arrays 414 are supported by a heatsink 412 within a case 418. Preferably, 3 or more tilt correcting mirrors 416 are used to combine the outputs of the laser diode arrays 414 15 into a highly collimated output beam. Preferably, each module 410 advantageously includes P laser diodes. It will be appreciated that the only significant limit on the number P is the number of laser diodes which can be effectively

It should be noted that the modules 410, while similar to those disclosed in U.S. Pat. No. 5.212,707 in some respects, are significantly different in a number of other respects. The modules described in U.S. Pat. No. 5.212.707 were actually fabricated and tested as part of a 100 watt fiber coupled system that was sold by the assignee in 1993. While these modules produced highly collimated laser diode arrays. there have since been several new developments in technology that have enabled the modules 410 to be enhanced vis-a-vis those disclosed in U.S. Pat. No. 5.212,707. For example, the basic emitters used in the patent were index guided devices, i.e., rib lasers. In contrast, the modules 410 according to the present invention advantageously can be gain guided structures, in particular, 20 micron wide oxide defined stripes. While the laser diode array 414 does not produce the same divergence as the index guided structures described in U.S. Pat. No. 5.212,707, they do produce significantly higher output power levels. Moreover, the additional improvements that have developed since the '707 patent was issued include:

(a) The use of high power index guided devices, such those found in Model No. SDL 5410 by Spectra Diode Labs,

(b) The use of a tapered oscillator design which is. in 45 general, an oxide defined stripe but with a diverging wave-

(c) Improved binary optics, whereby it is no longer necessary to use a refractive element to share the power and collimate the light from the emitters. It will be appreciated that this latter improvement alone increases the effective fluence produced by each of the laser diode arrays 414.

Implementing all of these improvements collectively can dramatically increase the brightness of the module 410 over the original design used in the modules described in U.S. 55 Pat. No. 5,212,707.

It should also be noted that the module 410 illustrated in FIG. 8 includes pointing mirrors 416 in the basic module structure. These pointing mirrors are used to direct the output beam exiting the module 410 through the optical path 60 illustrated in FIG. 7 and into the optical fiber 470. Advantageously, the pointing mirrors 416 provide the fine adjustments required to achieve a high coupling efficiency to the optical fiber 470. It should also be noted that the first commercial systems according to U.S. Pat. No. 5,212,707 65 provided 100 watt output power by polarization coupling two of the laser diode arrays shown in FIGS. 2 and 3. This approach to intramodule coupling was discarded in favor of

the module configuration shown in FIG. 8, which advantageously decreases the overall size of module 410 while increasing fluence at the workpiece.

Another improvement to the basic design of the modules 410 is the use of stackable microchannnel coolers to increase 5 the packing density of the laser diodes and consequently reduce the overall size of the system. Advantageously, cooling systems such as that disclosed in U.S. Pat. No. 5,495,490, which patent is incorporated by reference for all purposes, can be used.

Referring to FIG. 9, a preferred embodiment of the torch head 500 includes N collimating lenses 504, which receive output beams from optical fibers 470 via N fiber outputs 502 and which, in conjunction with transform lens 506, focus the N output beams onto a single spot. It will be appreciated that the output of M×N×P laser diodes are focused onto a single spot by torch head 500. Alternatively, it will be appreciated that the output of the LHAs 400 can be combined to end pump a solid state laser rod 510 using an identical or similar structure as that shown in FIG. 9. It should be mentioned that the number of collimating lenses in torch head 500 is N, the number of LHAs 400. It should also be mentioned that the laser rod 510 advantageously can be replaced by either a rare-earth doped optical fiber or a dye laser, i.e., any laser amplifying medium can be serially coupled to head 500.

As discussed above, the DLS 1 shown in FIG. 5 is for an exemplary case in which the output beams of four LHAs 400 are combined to deliver over 3200 watts of cw power to a single focusing lens 506. It should be noted that the output beam of each LHA 400 is produced by dichroic and polarization combining of the outputs of twelve modules 410.

It should be recognized that the output power of the DLS 1 can be varied in a number of ways. First, the number N of LHAs 400 can be varied. For example, doubling the number N of LHAs 400 would double the combined power of the 35 output beams. Alternatively, the number M of modules 410 and corresponding dichroic filters could be varied to vary the output power level. In an exemplary case, reducing the number M from 12 to 6 would halve the output power of that particular LHA 460. Finally, it should be noted that the 40 output power of the DLS 1 can advantageously be varied by controlling either the number M×N of system modules 410 energized or by controlling the excitation power level to some portion of the M×N modules 410. Although the output power can be adjusted by uniformly adjusting the excitation 45 current to the M×N modules 410, it will be appreciated that control at the upper and lower limits of system power may be difficult. For that reason, selected portions of the M×N modules may be controlled while the remainder of the M×N modules 410 may be either on or off, depending on the 50 desired system output power. It should also be recognized that the output power of the selected M×N modules 410 may be varied in accordance with excitation current in a cw operating mode or may be varied in accordance with duty cycle in a pulsed operating mode.

As discussed above, the output of each respective module is fiber coupled to an optical fiber 470. It should be noted that the transform lens 464 focuses and couples the entire output beam of LHA 400 into fiber 470. Preferably, the sine of the convergence angle as the light beam arrives at the light-receiving end of the fiber 470 is less than the numerical aperture NA of that fiber. Advantageously, the NA of the fiber 470 is less than 0.47. Preferably, the NA of the fiber 470 is \( \leq 0.19 \) and, most preferably, the NA of the optical power is \( \leq 0.16 \).

Preferably, the fiber coupling lens 464 is a lens designed specifically for focusing the collection of beams from the

wide wavelength band system of LHA 460 into the optical fiber 470. The number of modules 410 shown in the exemplary case illustrated in FIG. 7 was chosen to meet the optical power budget required at the fiber output and is entirely dependent on the quality of the optics used. As discussed previously, the only criteria is that the system produce 800 watts out of the fiber and be contained within a 0.16 NA.

Those of ordinary skill in the art will appreciate that the commercial applications range from surgery, to cutting, welding, and heat treating metals. In addition, this DLS 1 will be ideal for paint stripping, curing, cutting and drilling composite materials. Military applications range from an off-gimbal illumination system to a delay denial system for nuclear storage areas.

Another key application for this technology will be as an optical pump for solid state lasers, as discussed above, based on rare earth elements. This configuration facilitates excellent end pumping of a solid state laser rod, rare-earth doped fiber or dye laser. Moreover, this configuration has proven to be the most efficient means yet devised for converting incoherent laser diode pump light into a high quality. high brightness beam.

Although a presently preferred embodiment of the present invention has been described in detail hereinabove, it should be clearly understood that many variations and/or modifications of the basic inventive concepts herein taught, which may appear to those skilled in the pertinent art, will still fall within the spirit and scope of the present invention, as

30 defined in the appended claims.

What is claimed is:

1. A diode laser system, comprising:

N laser head assemblies (LHAs) generating N output beams, wherein each of said N LHAs includes:

- 35 M modules generating M laser beams, wherein each of said M laser beams has a different single wavelength;
  - M-2 dichroic filters, wherein each of said M-2 dichroic filters transmits a corresponding one of said M laser beams and reflects all other of said M laser beams;
  - a fiber coupling device collecting said M laser beams to produce a respective one of said N output beams;
    - N optical fibers receiving respective ones of said N output beams and generating N received output beams; and
- an optical assembly recollimating and focusing said N received output beams on a single spot.

where N and M are both integers  $\geq 2$ .

2. The diode laser system as set forth in claim 1, further comprising N LHA controllers controlling the output power produced by respective ones of said N LHAs.

3. The diode laser system as set forth in claim 1, further comprising a LHA controller controlling the output power produced by all of said N LHAs.

4. The diode laser system, as set forth in claim 1, wherein said optical assembly comprises:

N collimating lenses for recollimating respective ones of said N output beams; and

- a single transform lens focusing said recollimated N output beams onto said single spot.
- 5. The diode laser system as set forth in claim 4. wherein said single spot corresponds to one end of a solid state laser rod.
- 6. The diode laser system as set forth in claim 4. wherein said single spot corresponds to one end of a rare earth doped optical fiber.
  - 7. The diode laser system as set forth in claim 1, wherein each of said LHAs comprises:

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- M/2 first modules generating M/2 first laser beams, wherein each of said M/2 first laser beams has a corresponding single wavelength;
- (M/2)-1 dichroic first filters, wherein each of said (M/2)-1 dichroic first filters transmits a corresponding one of 5 said M/2 first laser beams and reflects all other of said M/2 first laser beams;
- M/2 second modules generating M/2 second laser beams, wherein each of said M/2 second laser beams has a corresponding single wavelength;
- (M/2)-1 dichroic second filters, wherein each of said (M/2)-1 dichroic second filters transmits a corresponding one of said M/2 second laser beams and reflects all other of said M/2 second laser beams;
- a polarizer coupling first and second M/2 laser beams to thereby produce M polarization coupled laser beams; and
- a fiber coupling device collecting said M polarization coupled laser beams to produce a respective one of said 20 N output beams.
- 8. The diode laser system as set forth in claim 1, wherein said each of said M-2 dichroic filters band pass filters said corresponding one of said M laser beams and reflects all other of said M laser beams.
  - 9. A diode laser system, comprising:
  - N laser head assemblies (LHAs) generating N output beams, wherein each of said N LHAs includes:
  - M first modules generating M first laser beams, wherein each of said M first laser beams has a different single wavelength;

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- M-1 first dichroic filters defining a first optical waveguide for directing all of said M first laser beams into a first optical path, wherein each of said M-1 first dichroic filters transmits a corresponding one of said M first laser beams and reflects all other said M first laser beams:
- a fiber coupling device disposed adjacent to said first optical path collecting said M first laser beams to 40 produce a respective one of said N output beams;
- N optical fibers receiving respective ones of said N output beams and generating N received output beams; and
- an optical assembly recollimating and focusing the N received output beams onto a single spot,

where N and M are both integers ≥2.

- 10. The diode laser system as set forth in claim 9, wherein said optical assembly comprises:
  - N collimating lenses for recollimating said N output beams; and
  - a single transform lens for focusing said recollimated N output beams onto said single spot.
- 11. The diode laser system as set forth in claim 10, wherein said single spot corresponds to one end of a laser 55 amplifying medium.
- 12. The diode laser system as set forth in claim 9, wherein each of said LHAs further comprises:
  - M second modules generating M second laser beams, wherein each of said M second laser beams has a 60 different single wavelength;
  - M-1 second dichroic filters defining a second optical waveguide for directing all of said M second laser beams into a second optical path, wherein each of said M-1 second dichroic filters transmits a corresponding 65 one of said M second laser beams and reflects all other said M second laser beams:

a rotating element for rotating the polarizations of said M second laser beams; and

a polarizer disposed at the intersection of said first and second optical paths coupling said M first and M second laser beams into the second optical path to thereby produce 2M polarization coupled laser beams thereby produce 2M polarization coupled has reliable to the coupling and the second optical path to the sec

wherein said fiber coupling device collects said 2M polarization coupled laser beams to produce a respective one of said N output beams.

13. The diode laser system as set forth in claim 9, wherein said fiber coupling device comprises a transform lens receiving and coupling said M first laser beams to one of said N optical fibers to thereby produce a respective one of said N output beams.

14. A diode laser system, comprising:

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means for generating N laser beams, wherein each of said N laser beams includes multiple wavelengths of light and wherein said generating means comprises:

M first means for generating M first laser beams, wherein each of said M first laser beams has a different single wavelength;

M-1 first filter means defining a first optical waveguide for directing all of said M first laser beams into a first optical path, wherein each of said M-1 first filter means transmits a corresponding one of said M first laser beams and reflects all other said M first laser beams;

fiber coupling means disposed adjacent to said first optical path for collecting said M first laser beams and for producing a respective one of said N output laser beams:

N optical fiber means receiving respective one of said N output laser beams for generating N received output beams; and

output means for recollimating and for focusing said N received output beams on a single spot,

where N and M are both integers  $\geq 2$ .

15. The diode laser system as set forth in claim 14, wherein said output means comprises:

N collimating lenses for recollimating said N×M laser beams; and

a single transform lens focusing said recollimated N×M laser beams onto said single spot.

16. The diode laser system as set forth in claim 14, wherein said single spot corresponds to one end of a solid state laser.

17. The diode laser system as set forth in claim 14, wherein said single spot corresponds to one end of a rare-earth doped optical fiber.

18. The diode laser system as set forth in claim 14. wherein said single spot corresponds to one end of a dye laser.

19. The diode laser system as set forth in claim 14, wherein said generating means further comprises:

second means for generating M second laser beams, wherein each of said M second laser beams has a different single wavelength;

M-1 second filter means defining a second optical waveguide for directing all of said M second laser beams into a second optical path, wherein each of said M-1 second filter means transmits a corresponding one of said M second laser beams and reflects all other said M second laser beams;

rotating means for rotating the polarizations of said M second laser beams; and

polarization means disposed at the intersection of said first and second optical paths for coupling said M first

# 13

and M second laser beams into said second optical path to thereby produce 2M polarization coupled laser beams,

wherein said fiber coupling means collects said 2M polarization coupled laser beams to produce a respective one 5 of said N laser beams.

20. The diode laser system as set forth in claim 19, wherein said fiber coupling device comprises a transform lens for receiving and for coupling said 2M polarization coupled laser beams to one of said N optical fiber means to thereby produce a respective one of said N output beams.

21. A method for generating a high energy laser beam, comprising:

- (a) generating P collimated laser beams having an Mth wavelength;
- (b) repeating step (a) M times so as to produce M×P collimated laser beams having M different wavelengths;
- (c) coupling said M×P collimated laser beams into an optical path;

## 14

- (d) coupling said M×P collimated laser beams into an ith optical fiber to thereby produce a corresponding ith output laser beam, where i=1 to N;
- (e) repeating steps (a) through (d) N times to thereby generate N output laser beams;
- (f) recollimating said N output laser beams to produce N recollimated laser beams; and
- (g) focusing said N recollimated laser beams onto a single spot.
- 10 where M. N and P are integers ≥2.
  - 22. The method as set forth in claim 21, wherein step (c) comprises dichroically coupling said M×P collimated laser beams into said optical path.
- 23. The method as set forth in claim 21, wherein step (c) comprises dichroically and polarization coupling said M×P collimated laser beams into said optical path.
  - 24. The method as set forth in claim 21, wherein step (c) comprises polarization coupling said M×P collimated laser beams into said optical path.

\* \* \*

# Column 15

1	25, A diode laser system, comprising:
2	a laser head assembly generating an output beam, the laser head assembly including:
3	M modules which generate M laser beams, wherein each of said M laser beams has
4	a different single wavelength; and
5	M-2 dichroic filters, wherein each of said M-2 dichroic filters transmits a
6	corresponding one of said M laser beams and reflects all other of said M laser beams
7	into a predetermined optical path to produce said output beam,
8	where M is an integer $\geq 2$ .
1	26. A diode laser system, comprising:
2	a laser head assembly which generates an output beam, the laser head assembly including:
3	M modules which generate M laser beams, wherein each of said M laser beams
4	occupies a different wavelength band;
5	M-R dichroic filters, wherein each of said M-R dichroic filters transmits at least a
6	respective one of said M laser beams occupying a given wavelength band and reflects
7	all other of said M laser beams not occupying the given wavelength band; and
8	an optical device which combines said M laser beams to thereby produce said output
<b>5</b>	beam,
ā	wherein:
Ï	M and R are positive integers; and
2	M is an integer $\ge 2$ .
1 <b>.</b> 17	
	27. The diode laser system as recited in claim 26, wherein the optical device comprises
2	means for collecting said M laser beams to thereby produce said output beam.
	· · · · · · · · · · · · · · · · · · ·
ī	28. The diode laser system as recited in claim 26, wherein the optical device comprises a
2	fiber coupling device which collects said M laser beams to thereby produce said output beam.
Ų.	
I	29. The diode laser system as recited in claim 26, wherein the optical device comprises a
$\frac{1}{2}$	polarization combiner which combines first selected ones of said M laser beams with second selected
3	ones of said M laser beams to thereby produce said output beam.
1	30. The diode laser system as recited in claim 29, wherein the first selected ones of said M
2	laser beams are equal in number to the second selected ones of said M laser beams.
1	31. A laser head assembly which generates an output beam including M laser beams
2	comprising:
3	M modules generating M laser beams, wherein each of said M laser beams has a different
4	single wavelength; and
5	M-2 dichroic filters, wherein each of said M-2 dichroic filters transmits a corresponding one
6	of said M laser beams and reflects all other of said M laser beams;
7	wherein M is an integer $\geq 2$ .

# Column 16

1 2	32. The laser head assembly as recited in claim 31, further comprising a fiber coupling device collecting said M laser beams to produce an output beam;
1	33. A method for generating a high energy laser beam, comprising:
2	(a) generating P collimated laser beams having an Mth wavelength;
3	(b) repeating step (a) M times so as to produce MxP collimated laser beams having M
4	different wavelengths; and
5	(c) coupling said MxP collimated laser beams into an optical path to produce a high energy
6	laser beam,
7	wherein M and P are integers $\geq 2$ .
1 2	34. The method as recited in claim 33, wherein the step (c) comprises dichroically coupling said MxP collimated laser beams into said optical path.
1 2	35. The method as recited in claim 33, wherein the step (c) comprises dichroically and polarization coupling said MxP collimated laser beams into said optical path.
	polarization coupling said with commuted ruser beams into said options public
	36. A diode laser system, comprising:
36.7 31.3	laser head assembly (LHA) which generates an output beam, the LHA including:
	M modules generating M laser beams, wherein each of said M laser beams has a different
<u> </u>	single wavelength;
14	M-1 dichroic filters defining an optical waveguide for directing all of said M laser beams into
¥3	the optical path, wherein each of said M-1 first dichroic filters transmits a corresponding one of said
6	M laser beams and reflects all other said M laser beams; and
7	a fiber coupling device disposed adjacent to the optical path for collecting said M laser beams
<b>78</b>	to thereby produce an output beam;
3	where M is an integer $\geq 2$ .
	37. A diode laser system, comprising:
2	laser head assembly (LHA) which generates an output beam, the LHA including:
3	M first modules generating M first laser beams, wherein each of said M first laser beams has
4	a different single wavelength;
5	M-1 first dichroic filters defining a first optical waveguide for directing all of said M first
6	laser beams into a first optical path, wherein each of said M-1 first dichroic filters transmits a
7	corresponding one of said M first laser beams and reflects all other said M first laser beams;
8	M second modules generating M second laser beams, wherein each of said M second laser
9	beams has a different single wavelength;
10	M-1 second dichroic filters defining a second optical waveguide for directing all of said M
11	second laser beams into a second optical path, wherein each of said M-1 second dichroic filters
12	transmits a corresponding one of said M second laser beams and reflects all other said M second
13	laser beams;
14	a polarization combiner disposed at the intersection of said first and second optical paths

# Column 17

15	which coupling said M first and M second laser beams into the second optical path to thereby
16	produce 2M polarization coupled laser beams; and
17	a fiber coupling device disposed adjacent to said first and second optical paths for coupling
18	said 2M polarization coupled laser beams to thereby produce the output beam.
19	where M is an integer $\geq 2$ .
1	38. A laser head assembly (LHA) which generates an output beam, comprising:
2	M modules generating M laser beams, wherein each of said M laser beams has a different
3	single wavelength;
4	M-R dichroic filters defining a first optical waveguide for directing all of said M laser beams
5	into a first optical path, wherein each of said M-R dichroic filters transmits at least one of said M
6	laser beams;
7	S second modules generating S laser beams, wherein each of said S laser beams has a
8	different single wavelength;
9	S-T dichroic filters defining a second optical waveguide for directing all of said S laser
10	beams into a second optical path, wherein each of said S-T dichroic filters transmits at least one of
П	said S laser beams;
12	a polarization combiner disposed at the intersection of said first and second optical paths
13	which couple said M and said S laser beams into a common optical path to thereby produce M + S
	polarization coupled laser beams; and
<b>1</b> 5	a fiber coupling device disposed adjacent to said first and second optical paths for coupling
16	said M + S polarization coupled laser beams to thereby produce the output beam.
17	wherein:
18	M, R, S and T are positive integers; and
<del>1</del> 9	at least one of M and S is $\geq 2$ .
	39. A diode laser system, comprising:
<u></u> 2	means for generating M laser beams, each of said M laser beams having a different
	wavelength;
<b>4</b>	M-R filter means defining a first optical waveguide for directing all of said M first laser
5	beams into an optical path, wherein each of said M-R filter means transmits at least one of said M
6	first laser beams; and
7	fiber coupling means disposed adjacent to said optical path for collecting said M laser beams
8	to thereby produce an output laser beam,
9	wherein M and R are both positive integers, and
10	wherein $M \ge 2$ .
1	40. A diode laser system, comprising:
2	first means for generating M first laser beams, wherein each of said M first laser beams has
3	a different single wavelength;
4	M-1 first filter means defining a first optical waveguide for directing all of said M first laser
5	beams into an optical path, wherein each of said M-1 filter means transmits a corresponding one of
6	said M first laser beams and reflects all other said M first laser beams;

said M first laser beams and reflects all other said M first laser beams;

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## Column 18

secon	d means f	or s	generating	M	second	laser	beams,	wherein	each	of	said	M	second	laser
beams has a c	lifferent si	ing	le waveler	igth	1;_									

M-1 second filter means defining a second optical waveguide for directing all of said M second laser beams into a second optical path, wherein each of said M-1 second filter means transmits a corresponding one of said M second laser beams and reflects all other said M second laser beams;

polarization combining means disposed at the intersection of said first and second optical paths for coupling said M first and said M second laser beams into said second optical path to thereby produce 2M polarization coupled laser beams; and

fiber coupling means disposed adjacent to said second optical path for collecting said 2M polarization coupled laser beams to thereby produce an output laser beam.

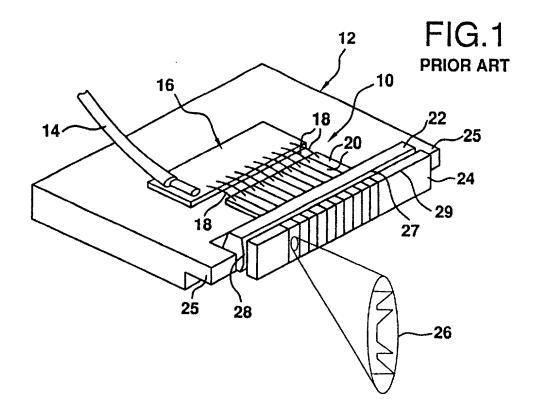
wherein M is a integer  $\geq 2$ .

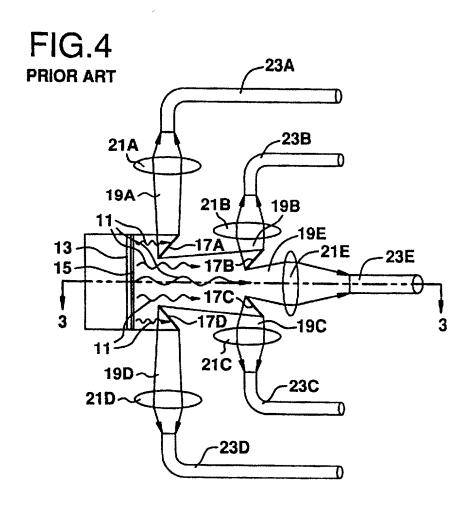
- 41. A method for generating a high energy laser beam, comprising:
- (a) generating P collimated laser beams having an Mth wavelength:
- (b) repeating step (a) M times so as to produce M×P collimated laser beams having M different wavelengths;
  - (c) coupling said M×P collimated laser beams into an optical path; and
- (d) coupling said M×P collimated laser beams into an ith optical fiber to thereby produce a corresponding ith output laser beam, where i=1 to N;

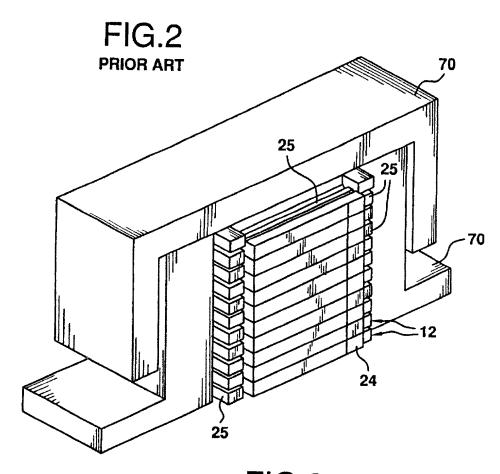
where M, N and P are positive integers and both M and  $P \ge 2$ .

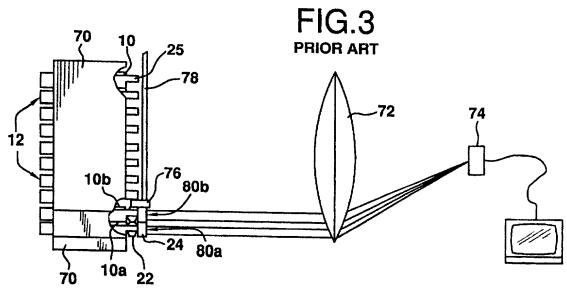
### ABSTRACT

A direct diode laser system includes N laser head assemblies (LHAs) generating  $\tilde{N}$  output beams. N optical fibers receiving respective N output beams and generating N received output beams, and a torch head recollimating and focusing the N received output beams onto a single spot. Preferably. each of the laser head assemblies of the direct diode laser system includes M modules generating M laser beams. wherein each of the M laser beams has a corresponding single wavelength of light, M-1 dichroic filters, wherein each of the M-1 dichroic filter transmits a corresponding one of the M laser beams and reflects all other wavelengths, and a fiber coupling device collecting the M laser beams to produce a respective one of the N output beams. In an exemplary case, the M-1 dichroic filters function as band pass filters. A method of generating a high fluence, high power laser beam is also described.









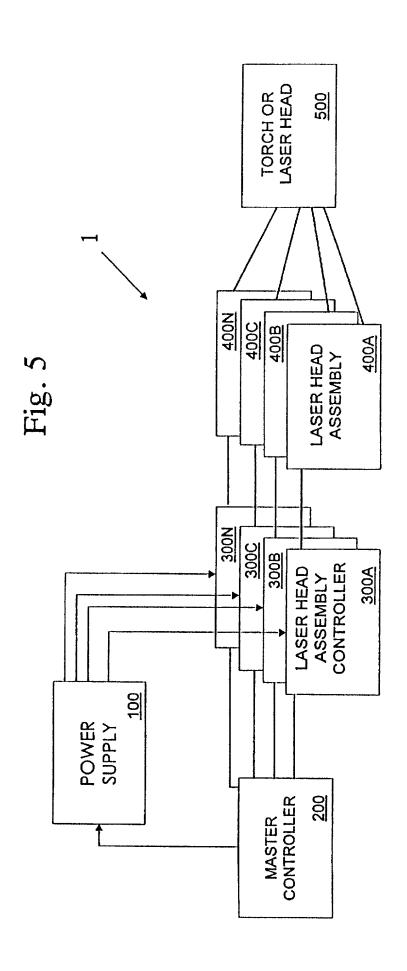
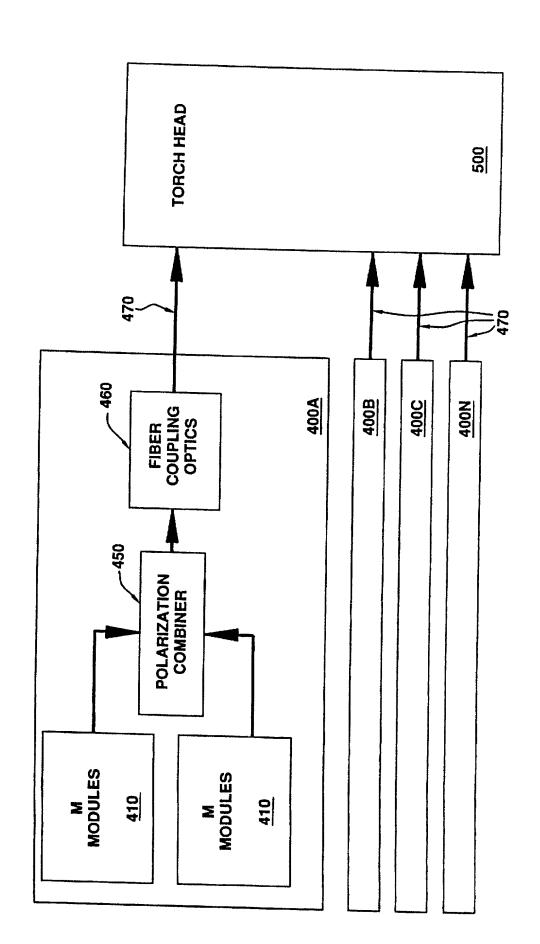


FIG.6



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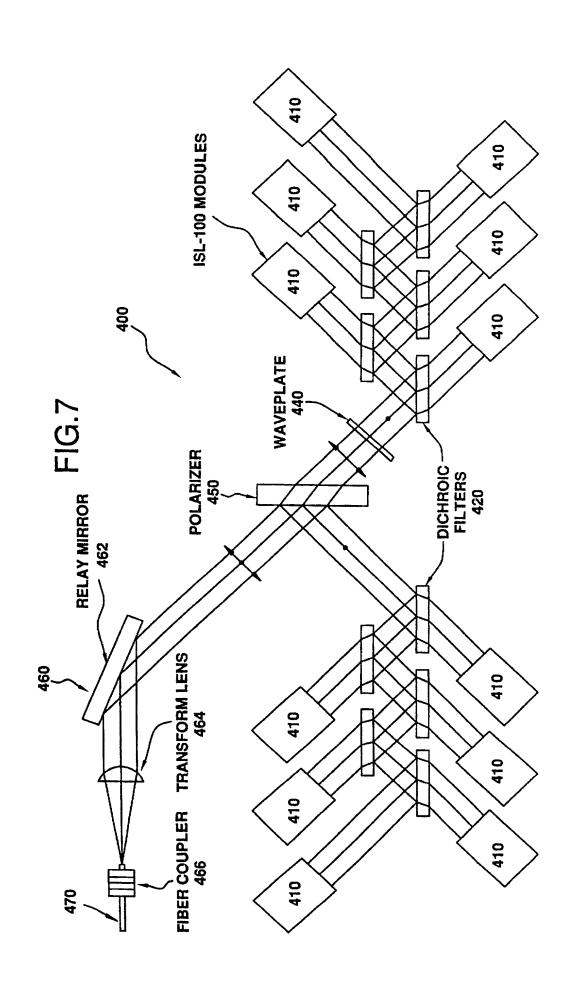


FIG.8

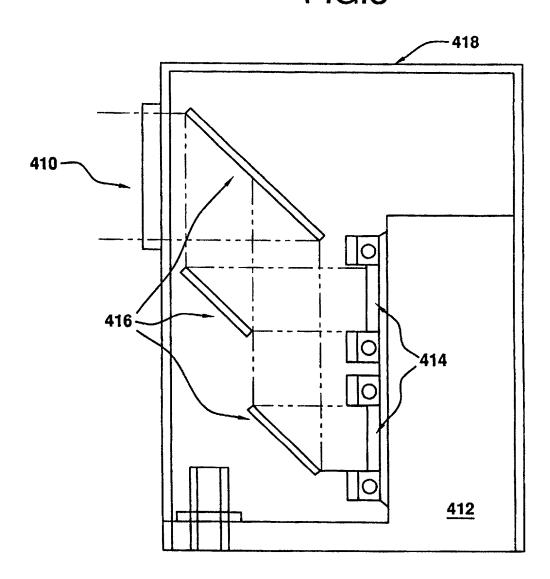
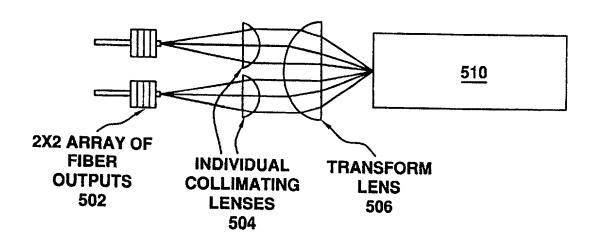


FIG.9



REISSUE APPLICATION DECLARATION BY THE INVENTOR	Docket Number (Optional) D-3953-RE
As a below named inventor, I horoby declare that:  My residence, mailing address and citizenship are stated below ne I believe I am the original, first and sole inventor (if only one name i joint inventor (if plural names are listed below) of the subject matter in patent number	is tisted below) or an original, first and r which is described and claimed, and for which a
is attached hereto.  X was filed onas reissue application null and was amended onN/A  (If applicable)	ımber 09/498,254
I have reviewed and understand the contents of the above identifie as amended by any amendment referred to above.  I acknowledge the duty to disclose information which is material to 37 CFR 1.56.  I verily bolieve the original patent to be wholly or partly inoperative below. (Check all boxes that apply.)	patentability as defined in
by reason of a defective specification or drawing.	
X by reason of the patentee claiming more or less than he had the	ne right to claim in the patent.
by reason of other errors. At least one error upon which reissue is based is described below. It reissue, such must be stated with an explanation as to the nature of	f the reissue is a broadening the broadening
In U.S. Patent No. 5,715,270, Applicants erroneously, a less than they were entitled to claim. For example, claim 1 of the	and without deceptive intent, claimed he '270 patent recited:
<ol> <li>A diode laser system, comprising:         N laser head assemblies (LHAs) generating N output be includes:         M modules generating M laser beams, wherein each of single wavelength;         M-2 dichroic filters, wherein each of said M-2 dichroic to of said M laser beams and reflects all other of said M laser beam     </li> </ol>	said M laser beams has a different

[Page 1 of 2]

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a fiber coupling device collecting said M laser beams to produce a respective one of said N butput beams;

N optical fibers receiving respective ones of said N output beams and generating N received output beams, and

an optical assembly recollimating and focusing said N received output beams on a single

where N and M are both integers > 2.

In doing so, Applicants erroneously claimed a diode laser system including at least two laser head assemblies. However, the laser diode system to which the Applicants believe they are entitled is as recited below:

25. A diode laser system, comprising:

a laser head assembly generating an output beam, wherein the laser head assembly includes: M modules which generates M laser beams, and wherein each of said M laser beams has a different wavelength band; and

M-2 dichroic filters, wherein each of said M-2 dichroic filters transmits a corresponding one of said M laser beams and reflects all other of said M laser beams into a predetermined optical path to produce said output beam; and

where M is an integer ≥2.

It will be appreciated from a comparison of claims 1 of the '270 patent and claim 25 of the Reissue application, the recitation of but a single laser head assembly permits additional elements, such as the N optical fibers of claim 1 to be omitted from the claimed diode laser system.

[Page 1**A** of 2]

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Country	United States						,
Telephone	(703) 706-5862		Fax	(703)	706-58	60	ı
or both, under 18 application, any pat Full name of sole or	willful false statements and U.S.C. 1001, and that such ent issuing thereon, or any particles first inventor (given name, far	willful false s atent to which	tatements	may je	opárdiz	e the va	
Mark S. Zediker		In.					
Inventor's signature			ate 				
Residence Same	as Mailing Address	Ċ	itizenship	Unite	ed Stat	tes	
Mailing Address	1005 Waneway Court, I	Florissant,	MO 6303	34-321	8		
	l joint inventor (given name,	family name)					
Robert R. Rice			-4.				
	Sint-1616			8 N2	camba	<u>. 20</u>	oυ
Residence Same a	as Mailing Address	Ç.	tizenship	United	d State	5	
	1736 Greenleaf Valley (		terfield l	MO, 63	3017		
i '	int inventor (given name, fan	nily name)					
John M. Haake	9						
Inventor's signature		D	ate 				
	as Mailing Address		itizenship		d State	es	
Mailing Address 5	Gum Tree Place, St. Ch	iarles, MQ,	63301-1:	296			
Additional joint inve	ntors are named on separately num	bered sheets att	sched hereto				

[Fage 2 of 2]

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REISSUE APPLICATION DECLARATION BY THE INVENTOR	Docket Number (Getlonal)  D-8953-RE
As a below named inventor, I hereby declare that:  My residence, mailing address and citizenship are stated below ne I believe I am the original, first and sole inventor (if only one name joint inventor (if plural names are listed below) of the subject matte in patent number 5,715,270 granted 02/03/1998 reissue patent is sought on the invention entitled HIGH EFFICIEN LASER SYSTEMS AND METHODS THEREFOR the specification of which	is listed below) or coriginal wast and r which is described and stained, and for which a
is attached hereto.  X was filed on 02/03/2000 as reissue application no and was amended on N/A (If applicable)	ımber <u>09</u> /498,254
I have reviewed and understand the contents of the above identified as amended by any amendment referred to above. I acknowledge the duty to disclose information which is material to 37 CFR 1.56.  I vorily believe the original patent to be whelly or partly ineperative below. (Check all boxes that apply.)	patentability as defined in
by reason of a defective specification or drawing.	
X by reason of the patentee claiming more or less than he had to	ne right to claim in the patent.
by reason of other errors.	
At least one error upon which reissue is based is described below. reissue, such must be stated with an explanation as to the nature o	
In U.S. Patent No. 5,715,270, Applicants erroneously, less than they were entitled to claim. For example, claim 1 of t	
1. A diode laser system, comprising:  N laser head assemblies (LHAs) generating N output be includes:  M modules generating M laser beams, wherein each of single wavelength;  M-2 dichroic filters, wherein each of said M-2 dichroic of said M laser beams and reflects all other of said M laser beams.	said M laser beams has a different filters transmits a corresponding one

[Page 1 of 2]

Burdan Hour Statement: This form is estimated to take 0,5 hours to complete. Time will very depending upon the needs of the individual case. Any comments on the amount of time you are required to complete this form should be sent to the Chief Information Officer. U.S. Patent and Trademark Office, Washington, DC 20231. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Assistant Commissioner for Patents, Washington, DC 20231.

Under the Paperwork Re	duction Act of 1995, no persons are required to respond	to a collection of ir	formation	unless it di	splays a valid	i OMB control number. r (Optional)
(REISSUE APPLIC	CATION DECLARATION BY THE INVE	NTOR, page :	2)	DOC	D-3953	B-RE
annicant As a pai	d in this reissue application arose wi med inventor, I hereby appoint the folions act all business in the United States P	wing attorne	v(s) an	o/or age	nus) to p	MOSECULE IIIIS
Name(s) Raymond H. J	Registration Number 34,231		,		<del></del>	
Robert A. Wes	<u>terlund 31,439</u>					
Ramon R. Ho	ch34,108				<del></del>	- A Section of the same
Correspondence A	ddress: Direct all communications about	t the applicati	on to:			
Customer Nu	ımber		<del></del>	1		Number Bar
	Type Customer Number	here		Code L	abel her	9
Firm or Individual Name	WESTERLUND POWELL, P.C.				<u></u>	
Address	122 N. Alfred Street					
Address			1		T	20044 2044
City	Alexandria	State	VA		Zip	22314-3011
Country	United States					
Telephone	(703) 706-5862 nat all statements made herein of my	Fax		706-58		
the knowledge that or both, under 18 application, any pa Full name of sole o	on and belief are believed to be true; and the like so twillful false statements and the like so U.S.C. 1001, and that such willful false tent issuing thereon, or any patent to where first inventor (given name, family name)	made are properties of the made are properties o	inisnar may j	jeopardiz	e and m ze the va	ibiisouneur
Mark S. Zediker Inventor's signature	1//// / 14 // // /	Date 12	/20	100	· · · · · · · · · · · · · · · · · · ·	N.S.F.
Residence Same	as Mailing Address	Citizenship		ted Sta	tes	
Mailing Address	315 Merlin Drive, St. Charles, MC	63304				
Full name of secon	d joint inventor (given name, family nam	ne)				
Robert R. Rice		TE .				
Inventor's signature		Date			000 m	AH
Residence Same	as Mailing Address	Citizenship	Unite	ed Stat	es	
	4736 Greenleaf Valley Drive, Ch		<u>MO, 6</u>	3017		
	oint inventor (given name, family name)			_		
John M. Haak Inventor's signature		Date (2	/2	0/0	0	, , , , , , , , , , , , , , , , , , ,
Residence Same	as Mailing Address	Citizenship	Unit	ed Sta	tes	
Mailing Address 5	Gum Tree Place, St. Charles, M					
	rentors are named on separately numbered sheet					

a fiber coupling device collecting said M laser beams to produce a respective one of said N output beams;

N optical fibers receiving respective ones of said N output beams and generating N received output beams; and

an optical assembly recollimating and focusing said N received output beams on a single spot,

where N and M are both integers ≥ 2.

In doing so, Applicants erroneously claimed a diode laser system including at least two laser head assemblies. However, the laser diode system to which the Applicants believe they are entitled is as recited below:

25. A diode laser system, comprising:

a laser head assembly generating an output beam, wherein the laser head assembly includes:
M modules which generates M laser beams, and wherein each of said M laser beams has a different wavelength band; and

M-2 dichroic filters, wherein each of said M-2 dichroic filters transmits a corresponding one of said M laser beams and reflects all other of said M laser beams into a predetermined optical path to produce said output beam; and

where M is an integer ≥2.

It will be appreciated from a comparison of claims 1 of the '270 patent and claim 25 of the Reissue application, the recitation of but a single laser head assembly permits additional elements, such as the N optical fibers of claim 1 to be omitted from the claimed diode laser system.

[Page 1A of 2]

Burden Hour Statement: This form is estimated to take 0.5 hours to complete. Time will vary depending upon the needs of the Individual case. Any comments on the amount of time you are required to complete this form should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, Washington, OC 20231. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS, SEND TO: Assistant Commissioner for Patents, Washington, DC 20231.

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REISSUE APPLICATION DECLARATION BY	Y THE ASSIGNEE	D-3953 TO I P			
I hereby declare that:		1			
My residence and mailing address and citizenship are stated below next to my name.					
I am authorized to act on behalf of the following assigne	ee: McDonnell Dougl	as Corpolation			
and the title of my position with said assignee is:	ef Counsel	PANEMARKOT			
The entire title to the patent identified below is vested in	said assignee.	TOE MINISTER STATE OF THE STATE			
Name of Patentee(s)		1,100			
Mark S. Zediker, Robert R. Rice, and John N	I. Haake				
Patont Numbor 5,715,270	Dato of Patont Issued <b>02/03/1998</b>				
Title of Invention High Efficiency, High Power Direct Doide Laser	Systems and Metho	ods Therefor			
I believe said patentee(s) to be the original, first and sol	e/joint inventor(s) of the	subject matter which is			
described and claimed in said patent, for which a reissu	e patent is sought on the	e invention entitled			
High Efficiency, High Power Direct Doide Lase	er Systems and Met	hods Therefor			
the specification of which					
is attached hereto.					
was filed on					
(If applicable)					
I have reviewed and understand the contents of the abo amended by any amendment referred to above.	ve identified specification	on, including the claims, as			
I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR 1.56.					
I verily believe the original patent to be wholly or partly in below. (Check all boxes that apply.)	noperative or invalid, for	the reasons described			
by reason of a defective specification or drawing.					
x by reason of the patentee claiming more or less t	han he had the right to o	claim in the patent.			
by reason of other errors.	Ü				
At least one error upon which reissue is based is describ	ed as follows:				
See Attached Sheet					
[Attach additional shee	ets, if needed.]				
All errors corrected in this reissue application arose without any deceptive intention on the part of the applicant					

# REISSUE APPLICATION DECLARATION BY THE ASSIGNEE

Docket Number (optional)

OIPE

In U.S. Patent No. 5,715,270, Applicants erroneously, and without deceptive intent, claimed less than they were entitled to claim. For example, claim 1 of the '270 patent recited: DEC 2 9 2000.

1. A diode laser system, comprising:

N laser head assemblies (LHAs) generating N output beams, wherein each of said MADEN includes:

M modules generating M laser beams, wherein each of said M laser beams has a different single wavelength;

M-2 dichroic filters, wherein each of said M-2 dichroic filters transmits a corresponding one of said M laser beams and reflects all other of said M laser beams;

a fiber coupling device collecting said M laser beams to produce a respective one of said N output beams;

N optical fibers receiving respective ones of said N output beams and generating N received output beams; and

an optical assembly recollimating and focusing said N received output beams on a single spot,

where N and M are both integers  $\geq 2$ .

In doing so, Applicants erroneously claimed a diode laser system including at least two laser head assemblies. However, the laser diode system to which the Applicants believe they are entitled is as recited below:

25. A diode laser system, comprising:

a laser head assembly generating an output beam, wherein the laser head assembly includes:
M modules which generates M laser beams, and wherein each of said M laser beams has a different wavelength band; and

M-2 dichroic filters, wherein each of said M-2 dichroic filters transmits a corresponding one of said M laser beams and reflects all other of said M laser beams into a predetermined optical path to produce said output beam; and

where M is an integer  $\geq 2$ .

It will be appreciated from a comparison of claims 1 of the '270 patent and claim 25 of the Reissue application, the recitation of but a single laser head assembly permits additional elements, such as the N optical fibers of claim 1 to be omitted from the claimed diode laser system.

Raymond H. J. Powell, Jr.  Robert A. Westerlund  31,439  Ramon R. Hoch  34,108  Correspondence Address: Direct all communications about the application to:  Customer Number  Type Customer Number Here  OR    Film or Individual Name   WESTERLUND POWELL, P.C.   Address   122 N. Alfred Street	I hereby appoint	the follo	wing attorney(s) and/or agent(s) States Patent and Trademark	) to pros	secute <b>t</b> h	is gor	D-395	3-DE	(O)
Correspondence Address: Direct all communications about the application to:  Customer Number  Type Customer Number Here  OR  Firm or  Individual Name  Address  City  Alexandria  Country  United States  Telephone  (703) 706-5862  I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statement were made with the knowledge that willful false statements and the like so made are punishable by fine and imprisonment, or both, under 18 U.S.C. 1001, and that such willful false statements may jeopardize the validity of the application, any patent issuing thereon, or any patent to which this declaration is directed.  Full name of person signing (given name, family name)  Righard J. Wickham, Chief Counsel  Signature  Address of Assigned  P O Box 516, St. Louis, MO, 63166-0516  Patentee  Mark S. Zediker  Residence/Mailing Address  315 Merlin Drive, St. Charles MO 63304	Name(s)		Regi	stration	Number	€	ner a	9 2000	
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Firm or Individual Name  WESTERLUND POWELL, P.C.  Address  City Alexandria  Country United States  Telephone (703) 706-5862  I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine and imprisonment, or both, under 18 U.S.C. 1001, and that such willful false statements may jeopardize the validity of the application, any patent issuing thereon, or any patent to which this declaration is directed.  Full name of person signing (given name, family name)  Richard J. Wickham, Chief Counsel  Signature  P O Box 516, St. Louis, MO, 63166-0516  Patentee  Mark S. Zediker  Residence/Mailing Address  315 Merlin Drive, St. Charles MO 63304	Customer N	lumber			<b></b>		Numi	ber Ba	· · · · · · · · · · · · · · · · · · ·
Sim or Individual Name   WESTERLUND POWELL, P.C.		-	Type Customer Number Here	<b>ə</b>			Labe	l Here	
Marie   Westerlund Powell, P.C.		T							**
City Alexandria State VA Zip 22314  Country United States  Telephone (703) 706-5862 Fax (703) 706-5860  I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statement were made with the knowledge that willful false statements and the like so made are punishable by fine and imprisonment, or both, under 18 U.S.C. 1001, and that such willful false statements may jeopardize the validity of the application, any patent issuing thereon, or any patent to which this declaration is directed.  Full name of person signing (given name, family name)  Richard J. Wickham, Chief Counsel  Signature  P O Box 516, St. Louis, MO, 63166-0516  Patentee  Mark S. Zediker  Residence/Mailing Address  315 Merlin Drive, St. Charles MO 63304	X Individual	WEST	ERLUND POWELL, P.C.					u.	
City Alexandria State VA Zip 2231.  Country United States  Telephone (703) 706-5862 Fax (703) 706-5860  I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statement were made with the knowledge that willful false statements and the like so made are punishable by fine and imprisonment, or both, under 18 U.S.C. 1001, and that such willful false statements may jeopardize the validity of the application, any patent issuing thereon, or any patent to which this declaration is directed.  Full name of person signing (given name, family name)  Richard J. Wickham, Chief Counsel  Signature  P O Box 516, St. Louis, MO, 63166-0516  Patentee  Mark S. Zediker  Residence/Mailing Address  315 Merlin Drive, St. Charles MO 63304	Address	122 N	. Alfred Street						
Country  United States  Telephone  (703) 706-5862  Fax  (703) 706-5860  I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statement were made with the knowledge that willful false statements and the like so made are punishable by fine and imprisonment, or both, under 18 U.S.C. 1001, and that such willful false statements may jeopardize the validity of the application, any patent issuing thereon, or any patent to which this declaration is directed.  Full name of person signing (given name, family name)  Richard J. Wickham, Chief Counsel  Signature  P O Box 516, St. Louis, MO, 63166-0516  Patentee  Mark S. Zediker  Residence/Mailing Address  315 Merlin Drive, St. Charles MO 63304	Address					<del></del>			
Telephone (703) 706-5862  I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statement were made with the knowledge that willful false statements and the like so made are punishable by fine and imprisonment, or both, under 18 U.S.C. 1001, and that such willful false statements may jeopardize the validity of the application, any patent issuing thereon, or any patent to which this declaration is directed.  Full name of person signing (given name, family name)  Richard J. Wickham, Chief Counsel  Signature  P O Box 516, St. Louis, MO, 63166-0516  Patentee  Mark S. Zediker  Residence/Mailing Address  315 Merlin Drive, St. Charles MO 63304	City	Alexa	ndria		State	VA		Zip	22314-30
I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statement were made with the knowledge that willful false statements and the like so made are punishable by fine and imprisonment, or both, under 18 U.S.C. 1001, and that such willful false statements may jeopardize the validity of the application, any patent issuing thereon, or any patent to which this declaration is directed.  Full name of person signing (given name, family name)  Richard J. Wickham, Chief Counsel  Signature  P O Box 516, St. Louis, MO, 63166-0516  Patentee  Mark S. Zediker  Residence/Mailing Address  315 Merlin Drive, St. Charles MO 63304									
statements made on information and belief are believed to be true; and further that these statement were made with the knowledge that willful false statements and the like so made are punishable by fine and imprisonment, or both, under 18 U.S.C. 1001, and that such willful false statements may jeopardize the validity of the application, any patent issuing thereon, or any patent to which this declaration is directed.  Full name of person signing (given name, family name)  Richard J. Wickham, Chief Counsel  Signature  P O Box 516, St. Louis, MO, 63166-0516  Patentee  Mark S. Zediker  Residence/Mailing Address  315 Merlin Drive, St. Charles MO 63304	Telephone	(703)	706-5862		Fax	(703	706-	5860	
Richard J. Wickham, Chief Counsel  Signature  Citizenship  Mark S. Zediker  Residence/Mailing Address  315 Merlin Drive, St. Charles MO 63304	statements made were made with fine and impriso jeopardize the v	de on info the know onment, o validity of	rmation and belief are believed wledge that willful false stateme ir both, under 18 U.S.C. 1001, a	to be tr nts and and that	rue; and t the like : such wil	furthei so ma liful fal	r that tl ide are Ise stat	hese s punisi tement	tatements hable by ts may
Address of Assigner  P O Box 516, St. Louis, MO, 63166-0516  Patentee Mark S. Zediker  Residence/Mailing Address 315 Merlin Drive, St. Charles MO 63304	Full name of pe	rson sigr J. Wickt	ning (given name, family name) nam, Chief Counsel						
P O Box 516, St. Louis, MO, 63166-0516  Patentee Citizenship Mark S. Zediker United States  Residence/Mailing Address 315 Merlin Drive, St. Charles MO 63304					Dat	ie/2/	120	120	93
Mark S. Zediker  Residence/Mailing Address 315 Merlin Drive, St. Charles MO 63304	Address of Assi	igne							
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Patentee Citizenship	315 Merlin D	rive, St.	Charles MO 63304		Τ.				
1 defices	Patentee						-		
Robert R. Rice United States			200		Uni	rea S	otates		
Residence/Mailing Address 14736 Greenleaf Valley Drive, Chesterfield, MO, 63017				), <mark>630</mark> 1	17				

List of Additional Patentees

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REISSUE APPLICATION DECLARATION BY THE ASSIGNEE  Docket Number (Optional) D-3953-RE					
Patentee John M. Haake		Citizenship United States			
Residence/Mailing Address					
5 Gum Tree Place, St. Charles, MQ, 63301-1296					
Patentee	Citizens	ship			
Residence/Mailing Address PEC 2 9 2000 .					
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Residence/Mailing Address	<u> </u>				
☐ Additional Patentees are named on separately numbered	sheets attache	ed hereto.			

STATEMENT UNDER 37 CFR 3.73(b)		
Applicant/Patent Owner: McDonnell Douglas Co	rporation	
Application No./Patent No.: 5,715,270	Filed/Issue Date: February 3, 1998	
Entitled: High Efficiency, High Power Direct Dioc	de Laser Systems and Methods Therefor	
McDonnell Douglas Corporation a P O Box	516, St. Louism MO, 63166-0516	
	ignee, e.g., corporation, partnership, university, government agency, etc.)	
states that it is:  1. <b>X</b> the assignee of the entire right, title, and interest;  2. an assignee of less than the entire right, title and The extent (by, percentage) of its ownership interest in the patent application/patent identified above by virtue.  A. <b>X</b> ] An assignment from the inventor(s) of the patent and Test was recorded in the United States Patent and Test.	est is% e of either:	
was recorded in the United States Patent and Tra which a copy thereof is attached.	ademark Office at Reel <u>0000</u> , Frame <u>0000</u> , or for	
OR		
B. [ ] A chain of title from the inventor(s), of the patent assignee as shown below:	application/patent identified above, to the current	
The document was recorded in the United S	, or for which a copy thereof is attached.	
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[ ] Additional documents in the chain of title are	e listed on a supplemental sheet.	
[ ] Copies of assignments or other documents in the cha [NOTE: A separate copy (i.e., the original assignment must be submitted to Assignment Division in accordar recorded in the records of the USPTO. See MPEP 30	It document or a true copy of the original document) Ince with 37 CFR Part 3, if the assignment is to be	
The undersigned (whose title is supplied below) is author	ized to act on behalf of the assignee.	
12/20/2000	Richard J. Wickham	
Date	Typed or printed name	
	/Signature	
	Chief Counsel	
	Title	